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FACTORS INFLUENCING STREAM TEMPERATURES

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Final Report IVa

(Experimental Facilities and Data Reduction Programs)

FACTORS INFLUENCING STREAM TEMPERATURES

Federal Water Pollution Control Administration

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September 1, 1968

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Final Report
Part IVa

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INTRODUCTION

The general import of stream temperatures has been commented on in various places in Reports I, II and III of projects funded under the same number and title. After the initial evaporation study reported in Final Report I, an attempt was made to investigate evaporation from actual streams. This study used the same technique for measuring evaporation as was reported in Part I and another technique as well. Using 6 small pans 8" x 8" set in the stream cooled by the stream subject to the same conditions as the stream, etc. it was hoped that the air structure above the water could be studied using a windmast and a hygrometer mast. The relationship of this air structure of wind and moisture would be related to the evaporated quantities.

Although it was possible to obtain a reasonably consistent average of evaporation rates from the above described pans, and the wind profiles were very consistent, yet the operation of the Cambridge Systems Hygrometer was very erratic.

Factory checks of the Hygrometer instrument indicated that it registered accurately in the 60 - 100% humidity range but not below 60% due to an elecrical short. Much information dependent on the humidity gradients was thus of no value.

It was therefore decided to attempt an evaporation study under closely controlled conditions in a laboratory model where erratic instrument behaviour could be quickly checked and taken care of. The project is thus a continuation of the stream evaporation studies under more favorable conditions.

PURPOSE AND SCOPE

The first report mentioned, under recommendations for research, the need to correlate the results of that report with a dynamic model or a prototype stream. This was part of the initially envisioned research aims but was not realized because the scope was beyond the availability of funds and personnel at that time. This initial study also showed that the air structure above a water surface may be considerably modified by the profile of the flowing stream surface. This continuation of the evaporation study takes up these objectives.

Because the primary intent of this effort was directed at the air structure evaporation relationship, all conditions of water flow and water temperature were held constant as much as possible for all tests conducted. In this way variations in windspeed and humidity could be introduced as the only major variables. Three stream profiles were investigated. Each was subjected to an identical series of wind and humidity conditions. During any one day the windspeed was kept constant and humidities were changed at the end of 2 to 3 hour test runs. During test runs an essentially steady state condition was obtained. On successive days the windspeed was changed and the same humidity series was introduced for comparable time periods. The objective was then to see if adequate knowledge of air structure conditions could be used with existing equations to predict more accurately the evaporation of a flowing stream and to relate the surface water profile to the evaporation parameters of this air structure. Thus some advancement of knowledge of the evaporation conditions in very turbulent and white water streams

with standing wave patterns and riffles was hoped to be gained.

Because of the vast amount of data generated by such experiments it was deemed necessary to program the solution of existing evaporation equations, as discussed in Part I, for a digital computer. A program encompassing several evaporation equations of major import and several empirical equations were thus programmed in such a way as to accept a common input of evaporation parameters. Although direct digital output would be preferable the cost of such equipment was beyond the project concept and financing. All data was therefore as much as possible graphically obtained and the necessary parameters obtained from the graphs and then prepared for evaporation program input.

EVAPORATION TEST FACILITY

The test facility was constructed in the engineering laboratory on the main campus at Oregon State University. This evaporation test system is composed of the following major components: The channel with associated basins, pump and fans, a 4 ton air conditioning unit available in the laboratory from the Department of Mechanical Engineering and the instruments for obtaining the necessary data. The facility will be discussed under these main categories.

CHANNEL

The channel as constructed is 24 ft. from end to end, 18" wide and 20" high. Two 24 ft. - 7" aluminum channels were placed on an axle located near the lower end of the channel to permit a change in the channel slope. The aluminum channel beams were carefully spaced to 18" width by wood blocks and ties.

On each end of the channel a stainless steel basin was attached to the channel by hanging these basins on the channel frame with an angle iron arrangement. A general view of the channel facility is shown in figure 1 during a test run.

The difficulty in keeping the channel waterproof, an absolute necessity in an evaporation study was overcome by careful construction methods, such as lapping the plastic joints where possible, seal gaskets at junctions from plastic to metal and end supports under each basin to releive any strain on the plastic. fig. 2. To prevent pump vibration from causing difficulties, both inflow and outflow connections were made aglexible. A 500 gpm 3 phase pump Cornell

Manufacturing Co. with a 6 inch intake and a 5 inch discharge pipe was sufficient to develop any flow velocity which could be desired, fig. 3. Flow was throttled with a butterfly valve with 5 positions, intermediate positions could be attained by taping the valve handle into intermediate positions.

The top of the channel was covered with plywood sheets covered with polyethylene. The polyethylene was necessary to provide sealing along the joints and also to present a similar smoothness of surface as the other sides of the channel.

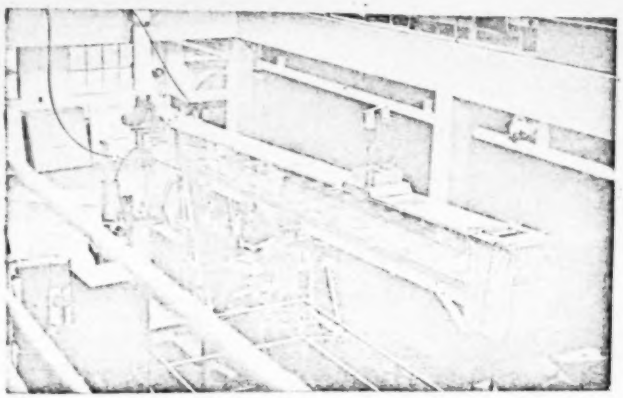
A squirrel cage fan was placed at each end of the channel. On the pushing end (fig. 2) if was necessary to channel the air by baffles, screens and hexagonal tubing to smooth the air flow to a uniform pattern over the entire channel cross section. On the sucking end it was only necessary to block the fan in to prevent it from pulling in outside air.

In addition the air conditioning unit also had air moving capability. Although adequate airflow could be obtained with this arrangement, it would have been more desirable to have a propellor fan with variable pitch or speed which would have given a wider range of possible air speeds.

The connection from the air conditioning unit is shown in fig. 2.

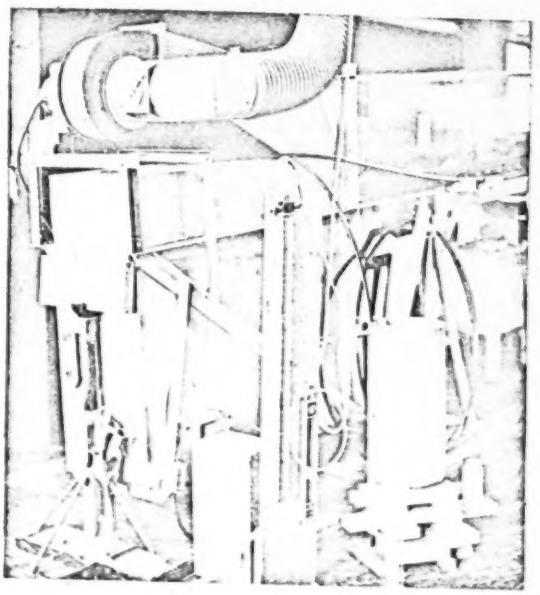
The channel was further equipped with three, 2500 watt, heating elements in order to vary the water temperature to whatever degree desired for either this or future experiments.

A recirculating pump could also take water from the intake basin and run it through the chiller of the refigerating unit of the air conditioner.



Mezzanine Floor View of
Evaporation Channel
Test Facility
fig. 1

1 Intake Basin at Lower End
of the Channel with Fan and
Connection to Air Condition-
ing Unit
fig. 2



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Mid-section of Channel
with Centrifugal Pump
fig. 3

Water temperature variations from 10^{o}C to 35^{o}C have been obtained. The upper limit has not been determined. All heating elements are engaged to achieve desired test conditions.

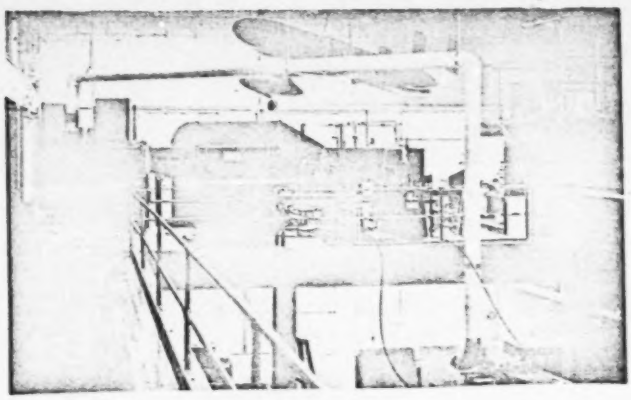
The wave configurations in the channel were developed by the placement of removable 8 ft. sections of aluminum corrugations of 2 different wavelength configurations. i.e. 12 and 18 inch from crest to crest and a depth from vally to crest of 3 inches. The sections had to be taped to the sides otherwise water entering at the connections of the sections would cause them to float.

AIR CONDITIONING UNIT

In figure 4 an overall view of the air conditioning unit is shown. The unit is located on the mezzanine floor and for that reason the long insulated pipe connection was required. This is a 4 - ton air conditioning unit built by American Blower Co. and Mechanical Engineering students. It is equipped to dry air to re-heat it, to moisten it to a desired humidity by baffling and by passing the dried air.

A water chiller is also part of this unit. The full capacity of the unit is obtained by 2 compressors operated in parallel. The capacity is such that it cannot simultaneously operate the chiller and the air drier at full capacity.

Humidity and temperature adjustments can be made with this unit to within a few percent of the desired humidity and a degree of the desired temperature.



View of Air
Conditioning Unit
fig. 4

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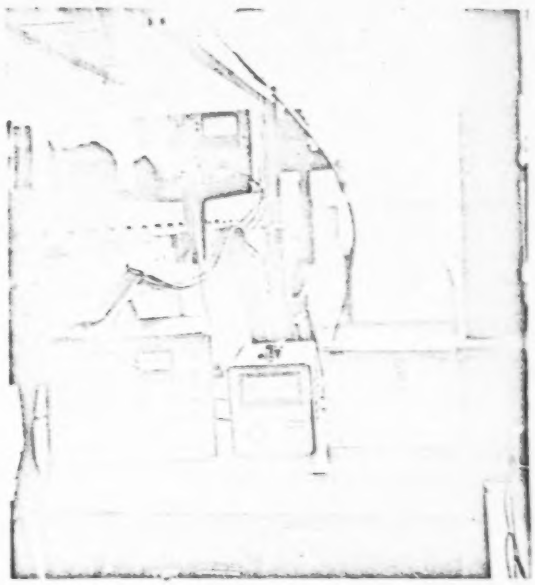
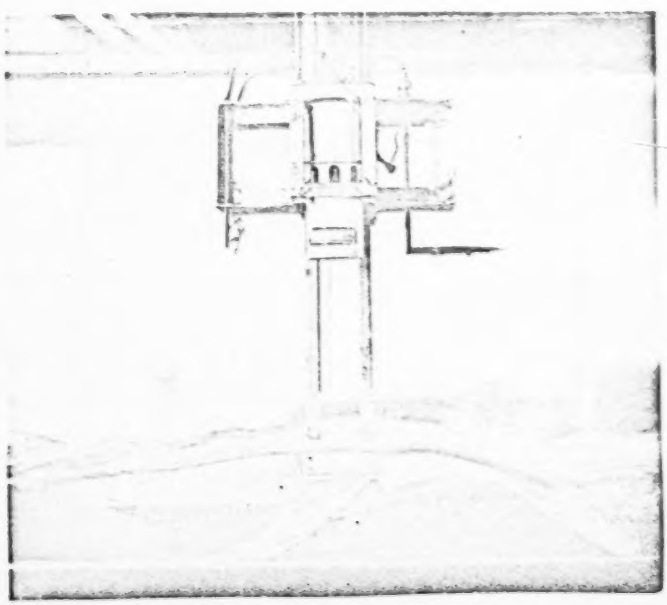


Measuring and Recording
Consoles
fig. 5



Moveable Dolly on
Vertical Guide
with Sensors for
Wind and Humidity
Fig. 6

DATA MEASURING EQUIPMENT

Basic observations for this experiment are water and wind speed, humidity at specific stations and elevations and temperatures at various locations for water and air. The recording and measuring consoles are shown in figure 5.

A DISA Hotwire Anemometer discussed in Part I and probes were used for both air and water velocity determinations. A Moseley X-Y Recorder also employed in the previous study to establish wind and humidity values as functions of their vertical position. A 10-turn linear potentiometer with a gear which ran along a vertical track fixed the position of the probe and other sensing devices as shown in fig. 6.

The potentiometer and sensing devices were mounted on a carriage or dolly which moved up and down through a pulley system operated by hand. By attaching a weight to the pully cord the dolly could be held stationary in any position.

The whole frame could be lifted out and moved to other stations along the channel.

A Cambridge Systems Vapor Mate Hygrometer was employed to measure the humidity and thus vapor pressure. This system which is a prime measurement device (meaning that it can be used as a calibration device for other humidity sensing instruments) has proved of very spasmodic reliability. It must be said that when it functions, it performs very well. It became necessary however to suspend its use during the last half of the test series because of faulty operation. Instead and as a check a pair of thermistors, the wet bulb thermistor aspirated seperately, were also installed on the dolly.

The aspirated Vapor Mate Humidity Sensor, the hot wire probe, and the dry and wet bulb thermistor are shown on the dolly in fig. 5, which figure also illustrates the surface configuration developed by the bottom profile which is responsible for this surface pattern. Thermistors were placed at the entrance and exit points of both air and water to measure air and water temperatures. All temperatures were recorded with calibrated Yellow Springs Thermistors and a Yellow Springs Telethermometer.

The whole study rested on the measurement of quantities of evaporated water. Since the surface of the basin is too large and oscillations are hard to slow down even at standstill, a glass tube was connected to the outside of the catch basin to determine water levels in the catch basin (fig. 2). Refilling and calibration procedures will be discussed under experimental procedure.

CALIBRATION OF MEASURING EQUIPMENT

The instrumentation calibration included the Hotwire Anemometer, Thermistor probes and the Vapor Mate Hygrometer correlation with wet and dry bulb thermistor readings.

Hotwire Anemometer Calibration

DISA Probes No. and were calibrated in a wind tunnel using a pilot tube for measuring wind velocities and comparing the voltage output of the Hotwire Anemometer to the comparable windspeeds. Because the probes are of the constant temperature type, meaning that actual windspeed differences can only be observed directly if the air temperature is constant, the probes had to be calibrated

at different temperature ranges. This was accomplished by setting the whole wind tunnel test unit in the evaporation channel and letting the air flow stabilize at a specified temperature and their calibrating each probe for that specific temperature. This permits a comparison of windspeeds between tests conducted at slightly different air temperatures and also to adjust vertical velocity profiles which are modified because of temperature profiles in the air stream.

Calibration of Thermistor Probes

Thermistors were calibrated in a water bath started at $0^{o}C$ in an ice bath. By stirring and adding hot water the temperature was raised to higher equilibrium levels at which time, the temperature response of a bundle of thermistors was recorded. A glass thermometer reading to $0.2^{o}C$ was inserted among the thermistors. The thermistor values, very consistent among themselves, varied from the glass thermometer up to $-0.5^{o}C$ in the range from 0^{o} - 40^{o} and by $+0.5$ - $1^{o}C$ above this temperature.

The Telethermometer temperature indicator boxes were then adjusted to have the thermistor readings agree, with the smallest possible deviation, with the glass thermometer.

Calibration of Wet and Dry Bulb Thermistors

A series of thermistor probes were equipped with absorbent material which when saturated with water and aspirated would give wet bulb temperature readings. Cotton, muslin and also a glass

embedded thermistor with muslin. Of this series there was very close agreement (1%) in the observed humidity values as checked with and indicated by the Vapor Mate Hygrometer.

TEST FACILITY OPERATING CHARACTERISTICS

The operating characteristics of the channel and its associated equipment provide for a range of water temperature from 10°C to 35°C+. The air temperature is dependent on the ambient air temperature in the building. During the winter months it may be possible to draw in cold air from outside but such was not attempted here.

Windspeeds in the channel section can reach 1.5 ft/sec with all fans going. Although a check valve was installed to regulate the air flow at the squirrel cage fan intake (see figure 2) it was not employed during the test runs.

The humidity range of the incoming air had a minimum of 20% and the maximum is saturation.

The bottom sections when placed in the channel produce a series of hydrautic jumps much on the order of a fish ladder. With the sections in place the volume of water passing through the channel will produce white water conditions at the third valve position and at position 4 a great deal of extra water must be added to prevent the pump from sucking air and causing violent jerking of the entire channel. Therefore the maximum operating range for these experiments has been at position 3. The slope may be varied from slack water conditions such as water flowing out of a deep pool over a sill to a positive slope of 10%.

EXPERIMENTAL PROCEDURE

At the start of a test run the pump was started until water circulated, then the pump was shut down. The water level in the water level indicator tube was then permitted to stabilize with the pump valve open. This level was recorded and then the connection between supply tank and the catchbasin was closed. At the end of a run the draw down was noted on the indicator tube and water was then resupplied from a graduated tank until the initial water was attained. Rhodanime B dye originally considered for use in determining evaporation volumes was not used due to previous experience indicating the absorption and adherence of dye to plastic and metal thus giving erroneous concentration values. Observations of the temperature of water and air were made at each end of the channel.

Three stations were established at uniform intervals along the channel. At the beginning and near the end of each test run a series of observations were made at each station of wind profile, humidity as functions of height. The dolly carriage was moved up and down manually at a slow speed to allow adequate response time for each sensor. The vertical motion was fed to the Y-leg of the Moseley X-Y Recorder and the X-leg received first the wind profile, then the hotwire anemometer and next the dry air and dew point temperature trace of the Cambridge Systems Vapor Mate Hygrometer. When the Vapor Mate failed to operate, dew point and dry air temperatures were recorded at 2-3 cm intervals along the vertical path as the dolly carriage was raised. Water speeds were recorded for all wave con-

figurations with silicone covered Hotfulm probe to determine water velocities at near the surface. Undulations of the water surface made it difficult to determine actual surface layer velocities except for very short instants.

The purpose of establishing stations along the channel was to investigate the moisture uptake of the air along the channel. This condition is somewhat analogous to dry air coming overlaid and then passing for a short period over a water mass, a frequently encountered condition in a stream.

DIGITAL COMPUTER PROGRAMS FOR EVAPORATION EQUATION AND DATA ANALYSIS

A. Sutton

B. Norris

C. Thornthwaite and Holzman

D. Model Emperical Formulea

E. Delay and Seaders

F. Air Space Structure Evaporation Formulas

G. Master

H, Computerized Preliminary Calculations

I. Basic Relationship and Conversion Formulea (1 through 9)

The program descriptions which follow each evaporation formula discussion, may be more easily understood by occasionally refering to their listings in the appendix. They were tested against manual calculations and were found to be in agreement to two decimal places. A discussion of the "Master" program which incorporates most of the evaporation programs is included. The programs which were written especially for this project, Slint 2 and Airstruct, were used more in the analysis than were the others.

A. Sutton:

$E(x_o,y_o) = G(\bar{u}_1)^{\left(\frac{2-n}{2+n}\right)} x_o\, y_o$ If there is an upwind water buffer zone.

$E(x_o,y_o) = G(\bar{u}_1)^{\left(\frac{2-n}{2+n}\right)} x_o^{\left(\frac{2}{2+n}\right)} y_o$ If upwind water buffer zone does not exist.

where: n = atmospheric stability parameter

$\bar{u}_1$ = average wind speed at z height above water surface (z is within the linear range of the log-wind profile) cm/sec

x_o = downwind length of the evaporation surface in cm.

y_o = crosswind length of the evaporation surface in cm.

$$G = (\psi_o - \psi_i)\left(\frac{2+n}{2-n}\right)^{\left(\frac{2-n}{2+n}\right)} * \left(\frac{2+n}{2\pi}\right) \sin\left(\frac{2\pi}{2+n}\right) \Gamma\left(\frac{2}{2+n}\right) a^{\left(\frac{2}{2+n}\right)} z_1^{\left(\frac{-n^2}{4-n^2}\right)}$$

where: ψ_o = water vapor content of the air at the water surface, gm/cm^3 ;

ψ_i = water vapor content of the ambient air, gm/cm^3 ;

z_1 = height above the water surface, cm;

Γ = gamma function

*Note, on page 30 of Part I, it appears incorrectly as: $\left(\frac{2+n}{2-n}\right)$ power $\left(\frac{2+n}{2-n}\right)$.

$$a = \frac{\left(\frac{\pi' K_o^2}{2}\right)^{(1-n)*}}{(1-n)(2-n)^{(2-n)}} \; (1-n)^{(1-n)} \; n^{(1-n)} \; z_1^{\left(\frac{n^2-n}{2-n}\right)} \; con$$

where: K_o = von Karman's constant = .4

$Con = \nu^n$ If water survace is smooth.

$Con = (\nu + U_* Z_o)^n$ If water surface is rough.

where: ν = Kinematic viscosity of the air, cm^2/sec;

Z_o = Roughness parameter

$$U_* = \frac{Uz}{5.75 \log_{10}(Z/Z_o)} \qquad \text{(Tichenor, 2)}$$

U_z = mean velocity of the air at height z, cm/sec.

Z = height in cm.

In order to obtain a value for ψ_o, water vapor content of the air at the water surface, the saturation vapor pressure at the water temperature (formula 1) was computed and used to find the density of the water vapor (formula 7).

For ψ_i, water vapor content of the ambient air, the saturation vapor pressure at the dew point temperature (partial vapor pressure) at sample height, z, (formula 1) was computed and used to find the density of the water vapor (formula 6).

For ν, Kinematic viscosity of the air, the air temperature was used in formula 3.

The program for evaluation of Sutton's evaporation formula is written to facilitate investigation of the influence the

*Note, on page 30 of Part I, it appears incorrectly as: $(\frac{1}{2}\pi' K_o^2)$ ....

atmospheric stability parameter has upon the evaporation rate. The atmospheric stability parameter is difficult to measure, thus it may be determined for an instalation emperically if one knows all the other parameters in the formula. Rather than solve for n, the stability parameter, the program will evaluate the expression for the evaporation rate using increasing values for n. The range and increment for n is determined by input data.

Inputs, order and definition:

N atmospheric stability parameter

S amount to be added to n each step

T top value desired for n

U velocity of the wind at height "H" above the water surface in cm/sec.

K dew point temperature at height "H" above the water surface in ^{o}C.

H height of samples in cm.

Z Z not, Z_o, the roughness parameter, in cm.

C water surface temperature in ^{o}C.

D air temperature at height "H" in ^{o}C.

X downwind length of evaporation surface in cm's.

L crosswind length of evaporating surface in cm's.

Y indicator variable: If the water surface is rough, $Y \neq 0$ and if the water surface is smooth, $Y=0$.

Ø indicator variable: If there exists a buffer zone, an evaporating surface upwind, $\emptyset \neq 0$ and if there is no buffer zone, $\emptyset = 0$.

Outputs:

First it prints the quoted string, "INPUTS ARE NSTUKHZCDXLYØ", then it gives their numerical values for the particular determination of the evaporation rate using Sutton's formula. Just under these numbers it indicates whether the water surface was rough or smooth and proceeds to give the computed evaporation rate and its units. Although the numerical value for n, the stability parameter, has been listed with the other data, it is once again listed, right along side the evaporation rate. This group of output lines is repeated until all the data has been processed. The groups are separated by two blank lines.

B. Norris:

$$E = \rho K_o \gamma_a \Gamma_b (q_o - q_b) u_a \quad \text{in } \#/ft^2\text{-sec.}$$

where: ρ = air density, lb/ft^3;

K_o = von Karman's constant = .4;

q_o = specific humidity at water temperature;

q_b = specific humidity at height b above the water surface;

u_a = wind speed at height a above the water, ft/sec.

If water surface is smooth:

$$\gamma_a = U_*/U_a, \quad U_* = U_z/[5.75 \log_{10} (Z/Z_o)]$$

$$\Gamma_b = 1/\ln (b/Z_o)$$

If water surface is rough:

$$\gamma_a = K_o/\ln (a/Z_o)$$

$\Pi_b = {}^{1}/_{\ln}\ ({}^{b}/_{2.41 * Z_o})$

In order to obtain a value for ρ, air density, formula 2 was used, using temperature or air in ^{o}C.

For q_s, specific humidity at water temperature, the saturation vapor pressure at the water temperature (formula 1) was computed and used in formula 4.

For q_b, specific humidity at height b above the water surface, the partial vapor pressure at the height b was computed with the dew point temperature at b by formula 1, this was used then in formula 4.

The program for evaluation of Norris's evaporation formula is rather straight forward. It contains a few checks for data input errors such as dividing by zero and taking the logarithm of non-positive numbers.

Input, order and definitions:

A temperature of air in ^{o}C at height "E" above water surface.

B temperature of surface water in ^{o}C.

C dew point temperature at height "E" above water surface in in ^{o}C.

D wind speed at height "E" above water surface in cm/sec.

E sample height above water surface in cm.

F Z not, Z_o, roughness parameter, in cm.

P atmospheric pressure in Hg.

W indicator variable: If the water surface is rough, $W \neq 0$ and if the water surface is smooth, $W = 0$.

Outputs:

First it prints the following quoted string "INPUTS ARE ABCDEFPW",

then it gives their numerical values for the particular determination of the evaporation rate using Norris's formula. Just under these numbers, after "DELTA Q =," it prints the numerical value of the specific humidity difference, $(q_o - q_b)$. The next line indicates whether the water surface was rough or smooth and proceeds to give the computed evaporation rate and its units. This group of output lines is repeated until all the data has been processed, the groups are separated by two blank lines.

C. Thornthwaite and Holzman:

$$F = \frac{.623\,\rho\,K_o^2\,(e_1-e_2)(U_2-U_1)}{\underline{P}\left[\ln\left(Z_z/\,Z_1\right)\right]^2} \qquad \text{(Tichenor, 4)}$$

where: $\underline{P}$ = atmospheric pressure, gm/cm^2;

ρ = density of air, gm/cm^3;

K_o = von Karman's constant = .4;

e_1 = vapor pressure at height Z_1 $\quad gm/cm^2$

e_2 = vapor pressure at height Z_2

U_1 = average wind speed at Z_1 $\quad cm/sec$

U_2 = average wind speed at Z_2

In order to obtain a value for ρ, air density, formula 2 was used.

For e_1, e_2, vapor pressures at corresponding heights Z_1, Z_2, the dew point temperatures at these positions were used in formula 1.

The program for evaluation of Thornthwaite's and Holzman's Formula is straight forward.

Inputs, order and definition:

A temperature of air in ^{o}C.

B dew point temperature at height "G" in ^{o}C.

C dew point temperature at height "H" in ^{o}C.

D wind speed at height "G" in cm/sec.

E wind speed at height "H" in cm/sec.

F atmospheric pressure in in Hg.

G height above the water surface for "B" and "D" in cm.

H height above the water surface for "C" and "E" in cm.

Outputs:

First it prints the following quoted string "INPUTS ARE ABCDEFGH", then it gives their numerical values for the particular determination of the evaporation rate using Thornthwaite's and Holzman's formula. Just under these numbers it indicates the computed evaporation rate and its units. This group of output lines is repeated until all the data has been processed, the groups are separated by a blank line.

D. Model Formulas (Tichenor, 6)

$E_1 = (A+Bu)\ (e_s - e_a)$

$E_2 = B'u\ (e_s - e_a)$

$E_3 = a(u)^b\ (e_s - e_a)$

where: e_s = saturation vapor pressure at temperature of water; mmHg.

e_a = vapor pressure of ambient air; mmHg.

u = wind velocity; ft/sec.

A, B, B', a, b, emperically developed coeffs.

E. Delay and Seaders: (Tichenor, 5)

$$E = \frac{M\ u\ (e_o - e_a)}{.262\ L}$$

where; M = usually 1.2 for river data, emperical mass transfer coefficient.

u = wind speed; miles/hr.

e_o = saturation vapor pressure at water temperature; mb.

e_a = vapor pressure of ambient air; mb.

L = latent heat of vaporization of water; cal/gm

In order to obtain a value for e_o, saturation vapor pressure at water temperature, formula 1 was used. For e_a, vapor pressure of ambient air, dew point temperature at sample height was used in formula 1.

For L, latent heat of vaporization of water, formula 5 was used, using the temperature of water.

The evaluations of Delay's and Seader's formula, and the model formulas are placed in one program because the sample data requirements are very similar.

Inputs, order and definition:

M emperical mass transfer coefficient for Delay and Seaders formula, usually = 1.2 for rivers

A emperical coefficient for "A" of model formula 1.

B emperical coefficient for "B" of model formula 1.

U wind speed at a constant height above the water surface in cm/sec.

S temperature of water at surface in ^{o}C

E dew point temperature of air in ^{o}C at the constant height which was used to determine "U".

J emperical coefficient "a" of model formula 3.

K emperical coefficient "b" of model formula 3.

C emperical coefficient "B" of model formula 2.

Outputs:

First it prints the following quoted string "INPUTS ARE MABUSEJKC", then it gives their numerical values for the particular determinations of the evaporation rate using Delay's and Seader's formula and the three model formulas. Just under there numbers it indicates the computed evaporation rates in the same indicated units. This group of output lines is repreated until all the data has been processed, the groups are separated by a blank line.

F. Air Structure Evaporation Formulas

$$E = \frac{(C+Du)(e_w-e_{oo})}{.262\ L}$$

$$E = \frac{P\,(u)^{Q}\,(e_w-e_{oo})}{.262\ L}$$

$$E = N + M\ \frac{(e_w-e_{oo})}{Z}\ \frac{u}{LG_{10}\ Z} + u_z\ \frac{e}{z} \quad \text{con}$$

where: e_w = saturation vapor pressure at water temperature; mb.

u_z = wind speed at height Z. cm/sec.

Z = height at which the wind speed was taken, could be standardized as the point just above the break in the vapor pressure

gradient. i.e. where $\frac{e}{Z}$ begins to change less rapidly and is tending more toward zero than toward infinity. cm.

$\frac{u}{lg_{10} Z}$ = slope of the linear portion of the plot, LG_{10} Z vs. U. cm/sec

$\frac{e}{Z}$ = slope of the linear portion above the break in the vapor pressure gradient. mb/cm

e_{oo} = vapor pressure at the point where the height is zero, as determined by an extrapolation of the linear portion above the break point. mb

u = wind speed at some height in the vicnity of the water surface, should be a constant height once the emperical coefficients are known. cm/sec.

L = Latent heat of vaporization. cal/gram.

C, D, P, Q, M, N are emperical coefficients

con = Units conversion factor = 55741.824

E = Evaporation rate in grams/ ft^2- min.

In order to obtain a value for e_w, saturation vapor pressure at water temperature, formula 1 was used. For e_{oo}, vapor pressure intercept extrapolated from vapor pressure gradient, either manually or by computer, a straight line was fit to their portion of the vapor pressure gradient which is indicated in the description of the parameter Z for the above formulas.

For L, latent heat of vaporization of water, formula 5 was used, using the temperature of the water.

C, D, P, Q, M, and N are computed by using program Slint 2.

The evaluations of the air structure evaporation formulas were placed in one program, airstruct, because the data requirements are similar.

Inputs, order and definition:

C emperical coefficient "C".

D emperical coefficient "D".

P emperical coefficient "P".

Q emperical coefficient "Q".

M emperical coefficient "M".

N emperical coefficient "N".

W water temperature, ^{o}C.

U wind speed at height Z, cm/sec.

Z height at which wind speed was taken, cm.

ES slope of the linear portion above the break in the vapor pressure gradient, mb/cm.

WS slope of the linear portion of the LG_{10} Z vs. U plot, cm.

ENOT vapor pressure at the point where the height is zero, as determined by an extrapolation of the linear portion above the break point, mb.

Outputs:

First it prints the following quoted string "INPUTS ARE CDPQMNWUZ,ES,WS,ENOT", then it gives their numerical values for the particular determinations of the evaporation rate using the air structure evaporation formulas. Just under these numbers it indicates the computed evaporation rates, all in the

indicated units. This group of output lines is repeated until all the data has been processed, the groups are separated by a blank line.

G. Master Program

This program is an evaluation program which essentially does what these programs do, Sutton; Norris; 1, 2, 3, Delay and Seaders; and Thornthwaite and Holzman. It reads in one set of data which is used in each of the programs, then the corresponding answers are printed along with the date-time. The form of this output is just as though the included programs were run one after the other repeatedly.

Inputs, order and definition:

CDNO =1, identifies type of input card, facilitates ordering the data deck.

DATE ten digit date and time integer for ordering the data deck.

IU height above the water for "JV" and "KW", cm.

UF height above the water for "RI", "WD" and "VE", cm.

QJ down wind length of evaporating surface, in cm.

PX cross wind length of evaporating surface, in cm.

OL if water is rough OL = 1, if water is smooth OL = 0.

AM if there is an upwind water buffer zone (i.e. not close to land) AM = 1, if there is no buffer zone, AM = 0

CO Delay and Seaders emperical mass transfer coefficient, M, = 1.2 for rivers usually.

DP emperical coefficient "A" from Slint program, for model evaporation formula number 1.

QE emperical coefficient "B" from Slint program, for model evaporation formula number 1.

(NEW CARD)

CDNO = 2.

DATE same ten digit date-time integer.

FR emperical coefficient "a" from Slint program, for model evaporation formula number 3.

GS emperical coefficient "b" from Slint program, for model evaporation formula number 3.

HT emperical coefficient "B" from Slint program, for model evaporation formula number 2.

TG air structure parameter, ZNOT, cm.

ZA atmospheric stability parameter, h.

YB amount to be added to ZA each step.

XC top value desired for ZA.

(NEW CARD)

CDNO = 3.

DATE same ten digit date-time integer.

XW wind speed at height "IU", cm/sec.

JV dew point temperature at height "IU", in ^{o}C.

WD wind speed at height "UF", cm/sec.

VE dew point temperature at height "UF", in ^{o}C.

RI air temperature at height "UF", in ^{o}C.

SH water temperature in ^{o}C.

BN atmospheric pressure in inhg.

LX if nest card should be numbered "1" then LX = 1, if next card should be numbered "3", then LX = 0. When LX = 0, this implies that the variables which are given values by the first two cards do not need to change. Thus they retain the values which they were assigned by the most recently read number one and two cards. However card three will contain new values for those variables which change most rapidly.

Outputs:

The output appears as though each of the programs, which together comprise Master, are printing out their answers right after one another, separated by blank lines.

H. Computerized Preliminary Calculations

In order to determine the A and B of model formula 1, for an evaporation system, obtain several sets of u (wind speed), E (evaporation rate), and (e_s-e_a) (vapor pressure driving force). Consider $E/(e_s-e_a)$ the Y-coordinate and u the X-coordinate of the several points generated from the given sets of u, E, and (e_s-e_a). Plotting these points:

one obtains a nearly straight line, this line has a slope = B and intercept = A.

Thus the equation is $\frac{E}{(e_s-e_a)} = A+Bu$

Program "slint" determines the least square straight line[7] and thus determines A and B.

In order to determine the B' of model formula 2, this is the same as $E = (A+Bu)(e_s-e_a)$ where $A = 0$. Thus when $E/(e_s-e_a)$ is plotted versus u as before, B' is the slope of the line which best approximates the line through the points generated, and the origin. The derivation of the method for finding this straight line and hence its slope is described in Part I, (Tichenor, 8).

Determination of the a and b of model equation 3, for an evaporation system proceeds as follows: Given many sets of u, wind speed, E, evaporation rate, and (e_s-e_a), vapor pressure driving force. Consider $\log_{10} (E/(e_s-e_a))$ the Y-coordinate and $\log_{10} u$ the X-coordinate of the many points which are generated from the given set of u, E, and (e_s-e_a).

Plotting these points:

one obtains nearly a straight line, this line has slope = b and intercept = $\log_{10} a$.

Thus the equation is $\log_{10} E/(e_s-e_a) = \log_{10} a+b \log_{10} u$

Program Slint determines the least-square straight line (Middlemiss,

7) and thus determines $\log_{10}$ a and b. However $a = 10^{\log_{10} a}$ thus ultimately determining a and b.

In order to determine the emperical mass transfer coefficient, M of the Delay and Seaders formula, for an evaporation system, obtain several sets of L, u, E, and $e_o - e_a$. Consider $E(.262)L/(e_o - e_a)$ the Y-coordinate axis and u the X-coordinate axis. When $E(.262)L/(e_o - e_a)$ is plotted versus u, M is the slope of the line which "best" approximates the line through the points generated, and the orgin. The technique is identical to that used to determine B' of model formula 2.

(Slint)

This program, Slint, determines the emperical coefficients for the model evaporation formulas. By least-square straight line determination of slopes and intercepts.

Inputs:

S temperature of water in ^{o}C.

T dew point temperature of air at a specific height, ^{o}C.

U wind speed at the same specific height as for "T", cm/sec.

V evaporation rate in grams/ft^2-min.

Since this program used least square techniques, this set of variables must be assigned at least three sets of values. When the data for these four variables is exhausted for a given evaporation situation, let the variable "S" take on the value "900" and the coefficients for the model formulas will be printed.

This procedure of supplying the program with several sets of the four variables terminating them with a "900" may be repeated until the data is all reduced.

Output:

First it prints the following quoted string "INPUTS ARE STUV", then it gives their numerical values in columns below. After the final set of data has been printed and the "900" has been read, it prints out the values for the emperical coefficients A, B, a, b, and B prime.

This sequence is repeated as long as the data holds out and conforms to the specifications.

As described in Part I, Page 23, "by plotting the logarithm of height versus velocity for a specific velocity profile, one can extrapolate the linear portion of the resulting curve to the point where the velocity is zero. The value of the intercept at this point is Z_o."

The program Slint takes several heights and wind velocities and produces a least-square straight line fit with a correlation coefficient to indicate the linearity of the points which happened to be used. The quantity $r = (XY) / ((X^2) (Y^2))^{\frac{1}{2}}$ is a unitless number in the interval -1,1 , which measures the direction and strength of the observed linear regression of $\log_{10}$ height on the air velocity, or vice versa, This number, r, generally is called the product-moment coefficient of linear correlation between $\log_{10}$ height and air velocity. (Fryer, 16)

(SLINT 2)

This program, Slint 2, determines the emperical coefficients for the air structure evaporation formulas and determines the air structure parameters, ZNOT, wind slope, e_{oo}, and vapor pressure slope. The basic technique is the same as that used in program Slint, least square straight line fit.

Inputs, order and definition:

DATE six digit, mo., day, year.

K number of heights from which samples are taken 3 K 8.

D(1) distance down wind from land for sampling station number 1.

D(2) distance down wind from land for sampling station number 2.

D(3) distance down wind from land for sampling station number 3.

BK break point in cm. Height at which $\frac{e}{Z}$ begins to tend toward zero.

H(1) H(2) H(K) the values for the "K" heights in cm. H(1) is lowest, H(K) is highest.

S sampling station's number from which the following data was collected.

TIME time at which this data was collected.

WT water temperature, ^{o}C.

EV measured evaporation rate in grams/ft-sq/min.

W(1) A(1) W(2) A(2) . : W(K) A(K) wind speeds and air dew point temperatures for the "K" height's in cm/sec and ^{o}F. W(1) is the wind speed for lowest height and W(K) is the wind speed for the hightest height. A(1) is the DPT for lowest height and A(K) is the DPT for the highest height.

M if M=0, the wave patterns are still the same as those of the last data and the sampling heights also are the same. If M=1, either the wave patterns have changed and/or the sampling heights have changed. Thus <u>if M = 0 the program reads the latter portion of this data list starting with the station number</u>, and if M = 1 the program prints out it's final answers for that configuration and starts reading the data list from the very start (i.e. variable "DATE" is first assigned and so on down the list).

Outputs:

A The date and the heights to be sampled from appear on the first line. Then a note describing the columns which follow to be organized such that the lowest height is represented by the top row and the highest height is represented by the lowest row.

B The time and station number are printed on the next line, with the water temperature and evaporation rate along side. Then the columns containing the wind speed, dew point temperature and the vapor pressure are printed. These columns are then followed on the next line by the values for ZNOT, the correlation coefficient for the wind parameters, wind slope, e_{oo}, the correlation coefficient for the vapor pressure parameters, and the vapor pressure slope. If the indicator variable, M, was = 0, then the block of output here labeled B is repeated until M = 1, then the block of output here labeled C is printed.

C then is followed with A, since the program is starting all over again.

C Station number which applies to the following averages, the average correlation coefficient for the wind parameters, the average of the "ZNOT"s computed, the average of the wind slopes computed, the average correlation coefficient for the vapor pressure parameters, the average vapor pressure intercept, e_{oo}, and the average vapor pressure slope all appear on one or two lines. Then the emperical coefficients C, D, P, Q, M, and N appear in columns with K rows. The top row for the coefficients which apply to data sampled from the lowest height and the bottom row for the coefficients which apply to data sampled from the highest height.

G. Basic Relationship Formulas:

1. Saturation vapor pressure:

$e_s = con\ (10)^{7.35*T/(231.77+T)}$; (T in ^oC)

If con = 4.58, e_s in mmHg

If con = 6.11, e_s in mb

The equation used here is derived by manipulation of one from Chow, Handbook of Applied Hydrology (9) to fit the tables given in Physics (10) by Henry Semat.

2. Air Density:

$$= \frac{\text{actual baro. press.}}{\text{stnd. baro press.}} \quad Da$$

$$Da = .00129311 + T_* (-4.8464153\ (10)^{-6} + T_* (1.8166032\ (10)^{-8}))$$

$\frac{grams}{cm^3}$ (T in ^oC)

This equation for Da is the least-square fit by 2nd degree polimonial, of table presented by Rouse (11).

3. Air Kinematic Viscosity:

$Va = .13117231 + T * (.00102264 - T * (1.8244857\ (10)^{-6})$

in cm^2/sec , (T in ^oC)

This equation is least-square fit by 2nd degree polinomial, of table presented by Rouse (11).

4. Specific Humidity:

$$SH = \frac{5}{8} \frac{e}{P - (3/8)e}$$

e: vapor pressure
P: baro. pressure

From Chow, Handbook of Applied Hydrology (12)

5. Latent Heat of Vaporization:

$$H_v = 597.3 - 0.56\ T \frac{cal}{gm} \qquad (T \text{ in } ^oC)$$

From Hydrology for Engineers (13)

6. Water Vapor Content of Ambient Air:

$$v = \frac{.622e}{R_v T}$$

e in mb: vapor pressure from dew point temp.

$R_v = 2.87\ (10)^3$

T in ^oC air temperature

From Handbook of Applied Hydrology (12) and from Hydrology for Engineers, (14)

7. Water Vapor Content of Air at Water Surface:

$$v = \frac{.622e}{R_v T}$$

e in mb: saturation vapor pressure at water temperature

T: water temperature ^oC

$R_v = 2.87\ (10)^3$

From Handbook of Applied Hydrology (12) and from Hydrology for Engineers (14).

8. The C. W. Thornthwaite associates wind profile register system model # 106 operating instruction manual presents a table for converting revolutions of cups per minute to cm/sec wind speed. Least-SQR approximation of table by 6th degree polinomial is:

where T = # turns / minute

speed in cm/sec = a+T*(b+T*(c+T*(d+T*(e+T*(f+T*(g))))))

where a = 12.620308

b = 2.4779937

c = .00111126

d = -.000009439223

e = $2.8202022 * 10^{-8}$

f = $-3.8222652 * 10^{-11}$

g = $1.9562249 * 10^{-14}$

```
'BEGIN'
'REAL''PROCEDURE' GAMMA(Z)..
     'VALUE' Z..'REAL' Z..
     'BEGIN''INTEGER' K..'REAL' P.T..'REAL''ARRAY' A(/0..9/)..
     A(/0/).=1.0..A(/1/).=.4227843370..A(/2/).=.4118402518..
A(/3/).=.0815782188..A(/4/).=.0742379076..
     A(/5/).=-.0002109075..A(/6/).=.0109736958..
     A(/7/).=-.0024667480..A(/8/).=.0015397681..
     A(/9/).=-.0003442342..
     T.='IF'Z'NOT GREATER'1'THEN'Z'ELSE''IF'Z'NOT GREATER'2'THEN'Z-1
                    'ELSE'Z-2..
     P.=.0000677106..
     'FOR'K.=9'STEP'-1'UNTIL'0'DO' P.=T*P+A(/K/)..
     GAMMA.='IF'Z'NOT GREATER'1'THEN'P/(Z*(Z+1))'ELSE''IF'Z'NOT GREAT
          ER'2'THEN'P/Z'ELSE'P..
     'END'..
'REAL'A,D, C, E, F, G, H, I, J, K, M, N, P, Q, R, S, T, U, V, W, X, Z..
'REAL' U1, H1, C1, D1, X1, K1..
'REAL' Y, O, L..
'COMMENT'          ************** SUTTON **************          ..
EOF(60,S6)..
S1..     INREAL(60,N).,  INREAL(60,S).,  INREAL(60,T)..  INREAL(60,U1).,
         INREAL(60,K1)., INREAL(60,H1).. INREAL(60,Z).,  INREAL(60,C1).,
         INREAL(60,D1)., INREAL(60,X1).. INREAL(60,L)..  INREAL(60,Y).,
         INREAL(60,O).,
S2..      U.=U1.,      H.=H1.,      C.=C1.,      D.=D1.,      X.=X1.,
K.=K1.,
OUTPUT(61,'('//,'(' INPUTS ARE NSTUKHZCDXLYO')',')'),.,
OUTPUT(61,'('3ZD.5D')',N,S,T,U,K,H,Z,C,D,X,L,  Y,O).,
     'IF' N 'NOT EQUAL' 1 'AND' N 'GREATER' 0 'AND'N 'NOT EQUAL'2'THEN'
'BEGIN' 'IF' Z 'NOT EQUAL' 0 'AND' H/Z 'GREATER'0'THEN''GO TO' S3..
'END'      ..
OUTPUT(61,'('''('     LN(H/Z)  OR N ERROR')'/')')..
'GO TO' S5..
S3.. A.=2-N..
V.=D..
E.=1-N..
V.=.13117231+V*(.00102264-V*(1.8244857* 10 'POWER' (-6))).,
C.=6.11*10'POWER'(7.35*C/(231.77+C))/C*2.167247386*0.0001.,
D.=6.11*10'POWER'(7.35*K/(231.77+K))/D*2.167247386*0.0001.,
F.=2*E..
G.=2+N    ..
I.=-E*N..
J.=G/A..
W.=6.283185307/G..
P.=(.2513274*N*A) 'POWER'E..
Q.=E*E 'POWER'E..
R.=J 'POWER'(1/J)..
```

```
J.=1/J.,
F.=A*G.,
F.=-N*N/F.,
W.=P/Q.,
P.=I/A.,
Q.=M/3.14159265358.,
R.=R/M.,
I.=W*H 'POWER' P..

'IF' Y =0 'THEN' 'BEGIN'
E.=V 'POWER'N.,
OUTPUT(61.'('''(' SMOOTH ')''')').,
'GO TO' S4..    'END'.,
E.=(V+U*Z*.4004       /LN(H       /Z)) 'POWER' N.,
OUTPUT(61,'('''(' ROUGH ')''')').,
S4.. M.=R*SIN(M)* GAMMA(Q) * H 'POWER' F.,
'IF'O'NOT EQUAL'0'THEN'R.=X*L'ELSE''BEGIN'R.=X'POWER'(2/(2+N))*L.,
OUTPUT(61.'('''(' NO BUFFER ZONE ')''')').,'END'.,
Q.=(I*E) 'POWER'Q*M*(C-D)*U'POWER'J*R.,
Q.=Q*5574'.824/(X*L).,
OUTPUT(61,'('''('IN GMS/SQ-FT-MIN  E(S)=')''')').,
OUTPUT(61,'('2ZDD.5D')',Q).,
OUTPUT(61,'('''('                N=')''')').,
OUTPUT(61,'('ZD.3D')',N).,
OUTPUT (61,'('/')').,
S5..'IF' N 'LESS' T 'THEN' 'BEGIN'
N.=N+S.,
'GO TO' S2..  'END'.,
'GO TO' S1.,
S6.. 'END'.,
```

Program Listing for Norris

```
'BEGIN'
'REAL' A, B, C, D, E, F,    J, K, P, W, DL,,
'COMMENT'          ************** NORRIS **************      ,,
EOF(60,S7),,
START,,   INREAL(60,A),,  INREAL(60,B),,  INREAL(60,C),,  INREAL(60,D),,
          INREAL(60,E),,  INREAL(60,F),,  INREAL(60,P),,  INREAL(60,W),,
OUTPUT(61,'('ZZ,'('INPUTS ARE ABCDEFPW')',')'),,
OUTPUT(61,'('3ZD.5D')',A,B,C,D,E,F,P,W),,
'IF' F 'NOT EQUAL' 0 'THEN' 'BEGIN'
J,=E/F,,
'IF'  J       'GREATER' 0 'THEN' 'BEGIN'
P,=P*33.8682714,,
'COMMENT'FROM INCHES HG TO MILLIBARS,,
A,=.00129311+A*(-4.8464153*10'POWER'(-5)+A*(1.5156032*10'POWER'(-5))),,
A,=A*P*.987166831*.001,,
'COMMENT' DENSITY NOW IN GRAMS/CM-CUBED,,
DL,=10 'POWER' (7.35*B/(231.77+B)),,
B,=30.55*DL/(8*P-18.33*DL),,
DL,=10 'POWER' (7.35*C/(231.77+C)),,
C,=30.55*DL/(8*P-18.33*DL),,
'COMMENT' NOW DELTA Q HAS NO UNITS,,
OUTPUT(61,'('/')'),,
P,=B-C,,
OUTPUT(61,'('''('DELTA Q =  ')''')'),,
OUTPUT(61,'('ZZZ.5D')',P),,
OUTPUT(61,'('/')'),,
J,=LN(J),,
K,=A*(B-C)*D*.4,,
'IF' W 'NOT EQUAL' 0 'THEN' 'BEGIN'
K,=K*.4/((J-.87963)*J),,
OUTPUT(61,'('''('ROUGH  ')''')'),,
'GO TO' PRINT,,
'END',,
K,=K*.4004429581/(J*J),,
OUTPUT(61,'('''('SMOOTH  ')''')'),,
PRINT,, OUTPUT(61, '('''(' IN GM/FT-SQ-MIN,  E(N)= ')''')'),,
K,=K*55741.824,,'COMMENT' FROM GM/CMSQ-SEC TO GM/FTSQ-MIN,,
OUTPUT(61,'('2ZZD.5D')',K),,
OUTPUT (61,'('/')'),,
'GO TO' START,,
'END',, 'END',,
OUTPUT(61,'('''(' LN(E/F)  BAD')'/')'),,
'GO TO' START,,
S7,, 'END',,
```

Program Listing for Thornthwaite and Holzman

```
'BEGIN'
'REAL'   A, B, C, D , E, F, G, H, I.,
'COMMENT'                    ********** THORNTHWAITE AND HOLZMAN******.,
EOF (60,T1).,
START..   INREAL(60,A).,  INREAL(60,B).,  INREAL(60,C).,  INREAL(60,D).,
INREAL(60,E).,  INREAL(60,F).,  INREAL(60,G).,  INREAL(60,H).,
OUTPUT (61,'('//,'('INPUTS ARE ABCDEFGH')',/')'),.,
OUTPUT (61,'('2ZD.6D')',A,B,C,D,E,F,G,H).,
I.= -4.8464153*10 'POWER' (-6)+A* 1.8166032 *10 'POWER' (-5).,
A.=(.00129311+A*I)*F*.033433634.,
'COMMENT' A, AIR DENSITY IS IN GM/(CM CUBED) .,
B.=6.11*10'POWER' (7.35*B/(231.77+B)).,
C.=6.11*10 'POWER' (7.35*C/(231.77+C)).,
F.=F*33.8682714.,
'COMMENT' F, ATMOSPHERIC PRESSURE IS IN MB OR GM/CM-SQ.,
F.=((B-C)*(E-D)*5556.34501632*A)/((LN (H/G)) 'POWER' 2 * F).,
'COMMENT'(.16)(929.0304CM-SQ)/(FT-SQ)(60SEC)/(MIN)(.623)=5556.34501632.,
OUTPUT(61, '('/,'('IN GRAMS /FT-SQ-MIN    ,E(T,H)= ')''')'),.,
OUTPUT(61,'('2ZD.4D')',F).,
'GO TO'  START.,
T1..  'END'.;
```

Program Listing for 1, 2, 3, Delay and Seaders

```
'BEGIN'
'REAL' A, B, C, D, E,    G, H, J, K, L, M, S, U, V, X, Z;;
FOR (60, D2);;
'COMMENT'     ********** 1, 2, 3, +(D+S)  **********    ;;
D1;;INREAL(60,M);;
INREAL(60,A);;
INREAL(60,B);;
INREAL(60,U);;
INREAL(60,S);;
INREAL(60,E);;
INREAL(60,J);;
INREAL(60,K);;
INREAL(60,C);;
OUTPUT (61,'('/,'('INPUTS ARE MABUSEJKC')')');;
OUTPUT (61,'('3ZD.6D')',M,A,B,U,S,E,J,K,C);;
L.=S;;
L.=597.3-.56*L;;
U.=U*.03284;;
S.=4.58*10 'POWER' (7.35*S/(231.77+S));;
'COMMENT'  BOTH E AND S ARE IN MMHG HERE    ;;
E.=4.58*10 'POWER' (7.35*E/(231.77+E));;
Z.=S-E;;
X.=(A+B*U)*Z;;
W.=C*U*Z;;
H.=U 'POWER' K;;
H.=H*J*Z;;
D.=V*U*Z*3.4663839615/L;;
'COMMENT' (1011MP)(3600SEC)/((759MMHG)(5280FT)(.262))=3.4663839615 ;;
OUTPUT (61, '('/')');;
OUTPUT (61, '('''('IN GM/FT-SQ-MIN,  ')''')');;
OUTPUT (61, '('''('E(1)=')''')');;
OUTPUT(61,'('2ZZD.5D')',X);;
OUTPUT (61, '('''('    E(2)=')''')');;
OUTPUT(61,'('2ZZD.5D')',W);;
OUTPUT (61, '('''('    E(3)=')''')');;
OUTPUT(61,'('2ZZD.5D')',H);;
OUTPUT (61, '('''('  E(D+S)= ')''')');;
OUTPUT(61,'('2ZZD.5D')',D);;
OUTPUT (61, '('/')');;
'GO TO' D1;;
D2;; 'END';;
```

Program Listing for Master

```
'BEGIN'
'REAL''PROCEDURE' GAMMA(Z)..
     'VALUE' Z..'REAL' Z.;
     'BEGIN''INTEGER' K.;'REAL' P,T..'REAL''ARRAY' A(/0..9/)..
     A(/0/).=1.0..A(/1/).=.4227843570..A(/2/).=.4115640510..
A(/3/).=.0815782188..A(/4/).=.0742379070..
     A(/5/).=-.0002109075..A(/6/).=.0109736958..
     A(/7/).=-.0024667480..A(/8/).=.0015397681..
     A(/9/).=-.0003442342..
     T.='IF'Z'NOT GREATER'1'THEN'Z'ELSE''IF'Z'NOT GREATER'2'THEN'Z-1
                'ELSE'Z-2..
     P.=.0000677106..
     'FOR'K.=9'STEP'-1'UNTIL'0'DO' P.=T*P+A(/K/)..
     GAMMA.='IF'Z'NOT GREATER'1'THEN'P/(Z*(Z+1))'ELSE''IF'Z'NOT GREAT
          ER'2'THEN'P/Z'ELSE'P..
     'END'..
'REAL'ZA,YB,XC,WD,VE,UF,TG,SH,RI,QJ,PK,OL,AM,BN,CO,DP,QE,FR,GS,HT,IU..
'REAL'JV,KW,LX,DATE,CONO,DATE1..
EOF(60,R3)..
R1..
INREAL(60,CONO)..'IF' CONO 'NOT EQUAL' 1'THEN' 'GO TO' Q1..
INREAL(60,DATE1)..
INREAL (60,IU )..
INREAL (60,UF )..
INREAL (60,QJ )..
INREAL (60,PK )..
INREAL (60,OL )..
INREAL (60,AM )..
INREAL (60,CO )..
INREAL (60,DP )..
INREAL (60,QE )..
INREAL(60,CONO)..'IF' CONO 'NOT EQUAL' 2'THEN''GO TO' Q1..
INREAL(60,DATE)..'IF' DATE 'NOT EQUAL' DATE1'THEN' 'GO TO' Q1..
INREAL (60,FR )..
INREAL (60,GS )..
INREAL (60,HT )..
INREAL (60,TG )..
INREAL (60,ZA )..
INREAL (60,YB )..
INREAL (60,XC )..
R2..
INREAL(60,CONO).. 'IF' CONO 'NOT EQUAL' 3'THEN'.'GO TO' Q1..
INREAL (60,DATE )..
INREAL (60,KW )..
INREAL (60,JV )..
INREAL (60,WD )..
INREAL (60,VE )..
INREAL (60,RI )..
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INREAL (60,SH )..
INREAL (60,SN )..
INREAL (60,LX )..
OUTPUT(61,'('3/, BZZBBZZBBZZBBB4D')',DATE)..
OUTPUT(61,'(' '('    **********************************')'/')')..
'BEGIN'
'REAL'A,D,  C, E, F, G, H, I, J, K, M, N, P, Q, R, S, T, U, V, W, X, Z..
'REAL' Y, O, L,U1,K1,H1,C1,D1,X1..

'COMMENT' 111111  ************** SUTTON **************'       ..
OUTPUT (61,'('/')')..
N.=ZA..S.=YB..T.=XC..U1.=WD..K1.=VE..H1.='JF..Z.=TG..C1.=Sh..
D1.=RI..X1.=QJ..L.=PK..Y.=OL..C.=AM..
S2..U.=U1..H.=H1..C.=C1..D.=D1..X.=X1..K.=K1..
OUTPUT(61,'('//,'(' INPUTS ARE NSTUKHZCDXLYO')''')')..
OUTPUT(61,'('-0.0D+3D')',N,S,T,U,K,H,Z,C,D,X,L,Y,O)..
     'IF' N 'NOT EQUAL' 1 'AND' N 'GREATER' 0 'AND'N 'NOT EQUAL'2'THEN'
'BEGIN' 'IF' Z 'NOT EQUAL' 0 'AND' H/Z 'GREATER'0'THEN''GO TO' S3..
'END'      ..
OUTPUT(61, '('''('    LN(H/Z)  OR N ERROR')'/')')..
'GO TO' S5..
S3.. A.=2-N..
V.=D..
E.=1-N..
V.=.1311723?1+V*(.00102264-V*(1.8244857* 10 'POWER' (-6)))..
C.=6.11*10'POWER'(7.35*C/(231.77+C))/ C*2.167247386*0.0001..
D.=6.11*10'POWER'(7.35*K/(231.77+K))/ D*2.167247386*0.0001..
F.=2*E..
G.=2+N    ..
I.=-E*N..
J.=G/A..
M.=6.28318530716/G..
P.=(.25132742* N*A) 'POWER'E..
Q.=E*F 'POWER'F..
R.=J 'POWER'(1/J)..
J.=1/J..
F.=A*G..
F.=-N*M/F..
W.=          P/Q..
P.=I/A..
Q.=M/3.14159265358..
R.=R/M..
I.=W*H 'POWER' P..
'IF' Y =0 'THEN' 'BEGIN'
E.=V 'POWER'N..
OUTPUT(61,'('''(' SMOOTH ')''')')..
'GO TO' S4..      'END'..
E.=(V+U*Z*.4004495/LN(H/Z))'POWER'N..
OUTPUT(61,'('''(' ROUGH ')''')')..
S4.. M.=R*SIN(M)* GAMMA(G) * H 'POWER' F..
'IF'O'NOT EQUAL'0'THEN'R.=X*L  'ELSE''BEGIN'R.=X'POWER'(2/(2+N))*L..
OUTPUT(61,'('''(' NO BUFFER ZONE ')''')')..  'END'..
O.=(I*E) 'POWER'O*M*(C-D)*U'POWER'J*R..
O.=O*55741.824/(X*L)..
```

```
OUTPUT(61,'('''('E(S)='')'')').,
OUTPUT(61,'('2ZZD.5D')'.Q)..
OUTPUT(61,'('''('                    N=')'')')'),.
OUTPUT(61,'('ZD.3D')',N)..
S5..'IF' N 'LESS        ' T 'THEN' 'BEGIN'
N.=N+S.,
'GO TO' S2.,  'END'.,
S6.. 'END'..
'BEGIN'
'REAL' A, B, C, D, E, F,    J, K, P, W, DL..
'COMMENT'  111111 ************** NORRIS **************      .,
A.=RI.,B.=SH..C.=VE.,D.=WD.,E.=UF..F.=TU.,P.=BN.,W.=OL.,
OUTPUT (61,'('2/')').,
OUTPUT(61,'('//,'(' INPUTS ARE ABCDEFPW')',')').,
OUTPUT(61,'('-D.8D'+3D')',A,B,C,D,E,F,P,W)..
'IF' F 'NOT EQUAL' 0 'THEN' 'BEGIN'
J.=E/F.,
'IF'  J       'GREATER' 0 'THEN' 'BEGIN'
P.=P*33.6632714.,
A.=.0012831+A*(-4.846415E-10'POWER'(-6)+A*(1.8166032*10'POWER'(-8))).,
A.=A*P*.9871668?1*.001..
          DL.=10'POWER'(7.35*B/(231.77+B)).,
B.=30.55*DL/(8*P-18.33*DL).,
          DL.=10'POWER'(7.35*C/(231.77+C)).,
C.=30.55*DL/(8*P-18.33*DL).,
OUTPUT (61,'('/')')..
J.=LN(J).,
K.=A*(B-C)*D*.4..
'IF' W 'NOT EQUAL' 0 'THEN' 'BEGIN'
K.=K**.4  /((J-.87953)*J).,
OUTPUT(61,'('''('ROUGH    ')'')')'),.
'GO TO' PRINT.,
'END'  .,
K.=K*.4004495817/(J*J)..
OUTPUT(61,'('''('SMOOTH    ')'')')'),.
PRINT.. OUTPUT(61,'('''('  E(N)= ')'')')'),.
K.=K*55741.824.,
OUTPUT(61,'('2ZZD.5D')',K)..
OUTPUT(61,'('/')')'),.
'GO TO' X1.,
'END'., 'END'.,
OUTPUT(61,'('''('  LN(E/F)  BAD')'/')')'),.
X1..
'END'.,
'BEGIN'
'REAL' A, B, C, D, E,    G, H, J, K, L, M, S, U, W, X, Z.,
'COMMENT'     ********** 1, 2, 3, +(D+S)  **********     .,
M.=CO.,A.=DP..B.=GE.,U.=WD.,S.=SH.,C.=VE.,J.=FR..K.=SS.,C.=MT.,
OUTPUT(61,'('3/,'(' INPUTS ARE MABUSEJKC ')'')')'),.
OUTPUT(61,'('-D.9D'+3D')'',M,A,B,U,S,E,J,K,C)..
OUTPUT (61,'('/')')'),.
L.=S.,
L.=597.3-.56*L.,
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U.=U*.03284.,
S.=4.58*10 'POWER' (7.35*S/(231.77+S)).,
E.=4.58*10 'POWER' (7.35*E/(231.77+E)).,
Z.=S-E.,
X.=(A+B*U)*Z.,
W.=C*U*Z.,
H.=D 'POWER' K.,
H.=H*J*Z.,
D.=M*U*Z*3.466383961S/L.,
OUTPUT (61. '('/')').,
OUTPUT (61. '('''('E(1)=')''')').,
OUTPUT(61.'('2ZZD.5D')'.X).,
OUTPUT (61. '('''('    E(2)=')''')').,
OUTPUT(61.'('2ZZD.5D')'.W).,
OUTPUT (61. '('''('    E(3)=')''')').,
OUTPUT(61.'('2ZZD.5D')'.H).,
OUTPUT (61. '('''('  E(D+S)= ')''')').,
OUTPUT(61.'('2ZZD.5D')'.D).,
X2.. 'END'.,
'BEGIN'
'REAL'   A, B, C, D , E, F, G, H, I.,
'COMMENT'                ********** THORNTHWAITE AND HOLZMAN******.,
A.=RI.,B.=JV.,C.=VE.,D.=KW.,E.=WD.,F.=GN.,G.=IU.,H.=UF.,
OUTPUT(61,'('4/,'('' INPUTS ARE ABCDEFGH ')''  ')').,
OUTPUT(61,'('-D.9D'+3D')'.A,B,C,D,E,F,G,H).,
I.= -4.8464153*10 'POWER' (-6)+A* 1.8166032 *10 'POWER' (-8).,
A.=(.0012931+A*I)*F*.033433634.,
B.=6.11*10'POWER' (7.35*B/(231.77+B)).,
C.=6.11*10 'POWER' (7.35*C/(231.77+C)).,
F.=F*33.8682714.,
'IF' ABS((B-C)*(E-D)*(H-G))*G*H'NOT GREATER'0'THEN''BEGIN'
OUTPUT(61,'('/,'('ERROR')'./,'(' ABS((B-C)(H-G)(E-D))GH IS LSS')''')').,
OUTPUT(61,'('''(' OR EQUAL TO ZEROE ')''')').,'GO TO ' X2.,'END'.,
F.=((B-C)*(E-D)*5556.34501632*A)/((LN (H/G)) 'POWER' 2 * F).,
OUTPUT(61, '('/.'(' E(T,H)= ')''')').,
OUTPUT(61.'('2ZD.4D')',F).,
X2..
OUTPUT (61,'('3/')').,
T1..  'END'..
'IF' LX 'EQUAL' 0 'THEN' 'GO TO' R2 'ELSE' 'GO TO' R1.,
Q1..OUTPUT(61.'('///,'('   DATA SEQUENCE IS MIXED')''')').,
R3..'END'.,
```

Program Listing for Slint or Preliminary Calculations

```
'BEGIN'
'INTEGER' I.,
'REAL' L,X.,
'REAL' A, B, C, D, E, F, G, H, J, K, M, N, P, Q, R, S, T, U, V, W, Y.,
'COMMENT'    SLOPE INTERCEPT          **********  SLINT  ********** .,
EOF (60,S3).,
S1..  A.=B.=C.= D.=E.=F.=G.=H.=  0.,
I.=2.,
OUTPUT (61,'('/,'('INPUTS ARE STUV')')').,
OUTPUT (61,'('/')').,
S2..      INREAL(60,S).,
'IF' S 'NOT EQUAL' 900 'THEN' 'BEGIN'
          INREAL(60,T).,  INREAL(60,U).,  INREAL(60,V).,
OUTPUT (61, '('3ZD.6D')',S,T,U,V).,
OUTPUT (61,'('/')').,
U.=U*.022308393.,
'COMMENT' U, WIND SPEED, IN FT/SEC.,
S.=4.58* 10 'POWER' (7.35*S/(231.77+S)).,
T.=4.58* 10 'POWER' (7.35*T/(231.77+T)).,
W.=S-T.,
'IF' U*V*W 'EQUAL' 0 'THEN' 'BEGIN'
OUTPUT(61,'('/,'('U,V,AND S-T CANT BE CLOSE TO ZERO')',/')').,
'GO TO' LOOP.,
'END'.,
Y.=V/W.,
'IF' Y 'NOT GREATER' 0 'THEN' 'BEGIN'
OUTPUT(61,'('/,'('V MUST HAVE THE SAME SIGN AS S-T')', /')').,
'GO TO' LOOP.,
'END'.,
J.=LN(Y)/2.302585093.,
K.=LN(U)/2.302585093.,
A.=A+U.,
B.=B+U*U.,
C.=C+U*Y.,
D.=D+Y.,
E.=E+K.,
F.=F+K*K.,
G.=G+K*J.,
H.=H+J.,
I.=I+1.,
'GO TO' S2.,
'END'.,
L.=I*D-A*A.,
X.=I*F-E*E.,
'IF' P*L*X 'EQUAL' 0 'THEN' 'BEGIN'
OUTPUT(61,'('/,'('IN THIS CASE, NEED A DIFF NUMBER DATA SETS')',/')').,
'GO TO' S1.,
'END'.,
```

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P.=C/B.;
N.=(I*C-D*A)/L.;
M.=(B*D-C*A)/L.;
R.=(I*G-H*E)/X.;
Q.=(F*H-G*E)/X.;
Q.=10 'POWER' Q.;
OUTPUT(61,'('''('  A= ')''')').;
OUTPUT(61,'('2ZD.6D')',M).;
OUTPUT (61, '('''('  B= ')''')').;
OUTPUT(61,'('2ZD.6D')',N).;
OUTPUT (61, '('''('   SMALL A= ')''')').;
OUTPUT(61,'('2ZD.6D')',Q).;
OUTPUT (61, '('''('   SMALL B= ')''')').;
OUTPUT(61,'('2ZD.4D')',R).;
OUTPUT (61, '('''('   B PRIME = ')''')').;
OUTPUT(61,'('2ZD.6D')',P).;
OUTPUT (61,'('//')').;
'GO TO' S1.;
LOOP..INREAL(60,S).;
'IF' S 'NOT EQUAL' 900 'THEN' 'BEGIN'
          INREAL(60,T).;  INREAL(60,U).;  INREAL(60,V).;
'GO TO' LOOP.;
'END'.;
'GO TO' S1.;
S3..  'END'.;
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FOOT NOTES

1. The Effect of Surface Configuration on Evaporation From a Porous Stream Model, by Bruce A. Tichenor, Thesis for Civil Engineering Ph.D., pages 29, 30, 31.
2. Ibid page 141.
3. Ibid pages 25, 26.
4. Ibid pages 26, 27.
5. Ibid page 83.
6. Ibid pages 19, 37.
7. Analytic Geometry, by Ross R. Middlemiss, Chapter 14, especially pages 230-233.
8. Tichenor, pages 91, 92.
9. Handbook of Applied Hydrology, edited by Ven Te Chow, pages 3-5.
10. Fundamentals of Physics, by Henry Semat, page 360.
11. Elementary Mechanics of Fluids, by Hunter Rouse, page 363.
12. Ven Te Chow, page 3-5.
13. Hydrology for Engineers, by Kinslem Kohler, and Pavlhus, page 14.
14. Ibid page 15.
15. Tichenor, page 23.
16. Concepts and Methods of Experimental Statistics, by H. C. Fryer, 1966, page 226.